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# SPATIAL DISTRIBUTION OF HUMAN GEOMORPHIC ACTIVITY IN THE UNITED STATES: COMPARISON WITH RIVERS

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## ABSTRACT

By some measures, the role of humans in shaping the landscape is now greater than that of any other geomorphic agent. This effect varies spatially. In the United States, it is greatest in the east where population density is highest, and particularly in West Virginia and neighbouring states where coal mining is added to more general earth-moving activities. For comparison, rivers in the United States move less soil, and their influence is greatest in the western part of the country where steep, sparsely vegetated slopes contribute to high sediment loads. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS: humans; geomorphic agents; rivers

## INTRODUCTION

Over a century ago, Marsh (1869, 1882) called attention to the role of humans in shaping the landscape. In many instances, the effects were inadvertent, often involving increased erosion or sedimentation resulting from human activities.

Today, humans move tremendous amounts of earth, and the activity is far from inadvertent. In the course of building roads and houses and of mining, our species displaces about 35 Gt of earth annually, worldwide (Hooke, 1994). No other geomorphic agent appears to be as effective, currently, in sculpting the surface of the Earth. For example, as the second most important agent, rivers presently deliver only *c.* 24 Gt of sediment to the oceans and interior basins each year, of which 10 Gt are estimated to be a direct result of agriculture (data of Milliman and Meade (1983) and Judson (1968) as interpreted by Hooke (1994)). In the course of meandering, rivers shift 20 to 40 Gt/a over short distances (Hooke, 1994).

To put these numbers in a different perspective, suppose that all the earth moved by humans in the United States in the activities mentioned above were to be dumped into the Grand Canyon. We would fill the canyon in less than 400 years! This is *c.* 0·01 per cent of the time it has taken the Colorado River to carve it.

Despite their prowess, humans are not given much press in textbooks on geomorphology. This is, in part, because there is less mystery and beauty surrounding the operation of a bulldozer or excavator than there is in the development of meanders, of beach cusps, or of a multitude of other landforms. However, as geomorphologists and responsible citizens of planet Earth, we must not ignore the impact we are having in shaping our home.

In order to further the study of our influence on the landscape, I examine herein the *spatial distribution* of human geomorphic activity in the United States and compare it with that of rivers. Before presenting the calculations, however, let me address the question of how such comparisons are best made.

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## COMPARING HUMAN GEOMORPHIC ACTIVITY WITH THAT OF TRADITIONAL GEOMORPHIC AGENTS

In order to compare the efficacy of various geomorphic agents, it is necessary to quantify them. The best approach to this is not obvious, however. Previously (Hooke, 1994), I noted that calculating the work done per unit time by an agent – that is, the force exerted to move a mass of soil or rock multiplied by the distance it was moved divided by the time required – would be an approach soundly based in physics, but unwieldy. A pebble, for example, is entrained by a mountain stream and deposited in a gravel bar some distance downstream, but what force was exerted on the pebble, and how long did it take to move it? Trying to estimate energy expenditure results in similar problems; most geomorphic agents move material to positions of lower gravitational potential, and thus release (potential) energy rather than consume it. Humans, in contrast, are as likely to move earth up hill as down.

All geomorphic processes that alter the landscape, however, do so by moving earth. A logical approach, therefore, is to evaluate the efficacy of geomorphic processes by measuring the mass or volume of material moved per unit time. This movement involves initiation of motion, motion, and cessation of motion. (Were we dealing with traditional geomorphic agents alone, we would use the terms 'erosion', 'transportation' and 'deposition', but 'erosion', in particular, does not seem appropriate for describing human excavations.) Features such as valleys, cirques and road cuts result from the initiation phase, while floodplains, moraines and landfills reflect cessation. In these examples, the agents of motion are, of course, rivers, glaciers and trucks, respectively.

As mass is conserved, we can assess the mass of material moved by measuring the size of the landform produced by either the initiation or the cessation of motion, or by measuring the rate of transport. Because we are concerned with processes that result in a lasting alteration of the landscape, the only caveat is that the distance of transport be unidirectional and appropriately long in comparison with the scale of the feature. Thus, earth turned up by a plough that then slumps or is washed back into a furrow within a few weeks would not qualify.

Both herein and in my earlier paper (Hooke, 1994), I have focused on transport rate when dealing with traditional geomorphic processes, and on initiation of motion when considering human activity. More recently (Hooke, 1998) I have also utilized features produced by humans at the cessation of motion, such as pyramids and buildings made of earthen materials. These have been purely pragmatic choices, dictated by the nature of the data available.

A complication is that much of the earth moved by humans is transported only short distances, whereas I have compared these masses with, for example, that delivered to the oceans by rivers. Perhaps a more appropriate comparison, in this case, would be with the mass of sediment relocated by rivers as they gradually change their courses through meandering. In this case the amounts moved are more nearly comparable, as best I can judge: 35 Gt $a^{-1}$ versus 20 to 40 Gt $a^{-1}$, respectively (Hooke, 1994). The calculations involved in this approach are tricky, however, because of the need to exclude, particularly in the case of traditional geomorphic agents, sediment particles that are moved and then replaced almost immediately by others, with no net change in the landscape.

An alternative might be to consider the visual impact of a geomorphic process. Here, humans excel. We immediately notice when earth is moved for a new building or a highway cut, but it normally takes detailed measurements to detect an equivalent amount of mass transfer by a traditional geomorphic agent. Visual impacts, however, are difficult to quantify.

In the present paper, I compare the mass of earth moved by humans within a 1° (latitude and longitude) grid cell with the mass of sediment contributed by that grid cell to the total reaching the ocean or interior basins by fluvial transport. While perhaps an imperfect compromise, I maintain that the combination of my numerical results with a qualitative assessment of the visual impact provides compelling evidence for the significance of humans as geomorphic agents. The comparatively coarse grid spacing was mandated by the fact that many of the required numbers had to be read from maps and entered into spreadsheets by hand, but it also serves to smooth the results, yielding what is probably a more realistic pattern.

 

## SPATIAL DISTRIBUTION OF HUMAN GEOMORPHIC ACTIVITY

In the United States, annually, humans move *c.* 0·8 Gt of earth in house construction, *c.* 3·8 Gt in mining and *c.* 3 Gt in construction of paved roads (Hooke, 1994). These estimates are based on readily available data on housing starts, on mineral production and on the length of highways in the USA. Their sum, 7·6 Gt, is probably a conservative estimate of the total mass of earth so moved, as activities such as the continuing construction and maintenance of nearly 600 000 km of logging roads (M. Dombeck, Chief, US Forest Service, TV interview, 19 June 1998), dredging of rivers and harbours, beach replenishment, construction of large buildings, and landscaping are not included.

Let us assume that house and road construction scale with the population. Thus, for each grid cell, the local population density in individuals per square kilometre is needed. Data were obtained from a 1:32 000 000 scale map (Espenshade, 1983, p.86) and are based on the 1980 census; no correction was made for the *c.* 20 per cent increase in population between 1980 and the present. Then, dividing the total amount of earth moved in house and road construction, 3·8 Gt $a^{-1}$, by the total population, $226{\cdot}5 \times 10^6$, and multiplying by the local population density, yields an estimate of the mass of earth moved per square kilometre in each grid cell.

Of the earth moved in mineral production in 1988 (US Bureau of the Census, 1991), the three largest contributions are from coal (1·2 Gt $a^{-1}$ including overburden), stone (1·1 Gt $a^{-1}$), and sand and gravel (0·86 Gt $a^{-1}$) (Hooke, 1994). The last two of these are normally found and used locally, so I assumed that their contribution to the amount of earth moved by humans in each grid cell also scaled with the population density.

Other minerals, of course, can only be mined where they are present. As the contribution of minerals other than coal is only 0·6 Gt $a^{-1}$ and is distributed among 42 mineral species, the largest of which is copper at 0·14 Gt $a^{-1}$ (including overburden moved), these were neglected.

To estimate the amount of earth moved in coal production in each grid cell, I first estimated the coal production for each state in 1988 by scaling up the production of that state in 1976 (Cuff and Young, 1980, p.49) in proportion to the increase in total production in the United States between 1976 and 1988. Dividing the coal production of the state by the number of grid cells in that state that were within or near areas of coal mining, obtained from a map at an approximate scale of 1:32 000 000 (Cuff and Young, 1980, p.18), then yielded an estimate of the mass of coal moved in each grid cell.

Finally, I estimated the amount of soil contributed to rivers by farming activity. To do this, I used Judson's (1968) estimate of the fraction of the sediment load of rivers attributable to agriculture, 10 Gt $a^{-1}$ worldwide, and scaled that to the United States in proportion to the relative land area of the United States compared with the world (exclusive of Antarctica). The result is 0·7 Gt $a^{-1}$. The total land area under cultivation in the United States is $3{\cdot}9 \times 10^6$ $km^2$ (USDC, 1990, p.61), so the mean sediment yield from agriculture is *c.* 180 t $km^{-2}$ $a^{-1}$, a value characteristic of pasture (USDA, 1977). Multiplying this by the area under cultivation in each grid cell (USDC, 1990, p.61) then yields an estimate of the sediment yield due to agriculture in that cell.

My estimate of the mass of earth moved by humans in each grid cell is the sum of the amounts due to house and road building; to coal, stone, and sand and gravel mining; and to agriculture. The resulting spatial distribution is shown in Figure 1a.

## SPATIAL DISTRIBUTION OF GEOMORPHIC ACTIVITY OF RIVERS

For comparison, let us make a similar estimate of the spatial distribution of river activity in the United States. As noted, the worldwide flux of clastic and dissolved sediment to the oceans and interior basins, exclusive of the effects of agriculture, is *c.* 14 Gt $a^{-1}$ (Hooke, 1994). Assuming that this yield scales with the land area, the US contribution is 1 Gt $a^{-1}$. Thus, our task is to estimate how much of this sediment is derived from each grid cell.

Summerfield and Hulton (1994, p.13,881) found that relief ratio and runoff, combined, accounted for over 62 per cent of the variance in denudation rates in major drainage basins of the world. Thus, I focused on these two variables. As a proxy for runoff, mean annual precipitation in each grid cell was obtained from a map (Espenshade, 1983, p.82). Sediment yield from a drainage basin with standard relief (defined below) was then

 

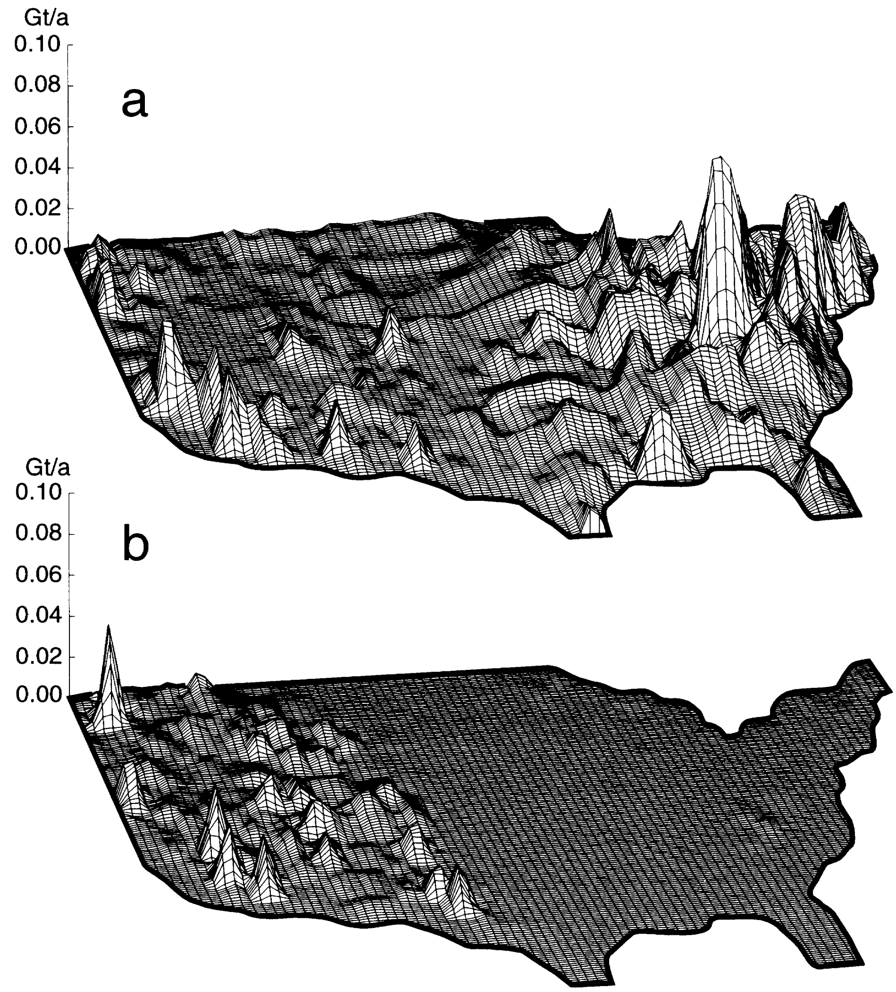


Figure 1. Maps of the United States showing, by variations in peak height, the rates at which earth is moved in gigatonnes per annum in a grid cell measuring 1° (latitude and longitude) on a side, by (a) humans, and (b) rivers

estimated with the use of the classic Langbein and Schumm (1958) curve, fully recognizing that there is considerable debate regarding the generality of this curve (e.g. Dendy and Bolton, 1976; Douglas, 1967; Ohmuri, 1983; Summerfield, 1994, p.393; Wilson, 1973).

To take variations in relief into consideration, I used a relation based on data of Summerfield and Hulton (1994): $Y = 10^{(0{\cdot}881\ +\ 0{\cdot}00168*R)}$, where $Y$ is millimetres of denudation per kiloyear and $R$ is the maximum difference in elevation within each grid cell in metres. In Summerfield and Hulton's study, the grid cells were 10 minutes of latitude or longitude on a side, and $R$ was averaged over the drainage basin. Herein, data on elevations at the grid nodes were obtained from a digital elevation model, and $R$ was taken to be the maximum of the differences in elevation between that node and the eight surrounding ones.

As both the definition of relief and the grid spacing used herein differ from those of Summerfield and Hulton, I could not use their relation directly. Instead I assumed that the effect of relief could be approximated by multiplying the sediment yield from the Langbein and Schumm curve by the ratio between the value of $Y$ from the Summerfield and Hulton relation, using the value of $R$ for the point in question in my grid, and the corresponding value for my standard drainage basin. The value of $R$ (400 m) for the standard drainage was chosen (scaled) to give a total sediment yield from the US of *c.* 1 Gt a$^{-1}$.

 

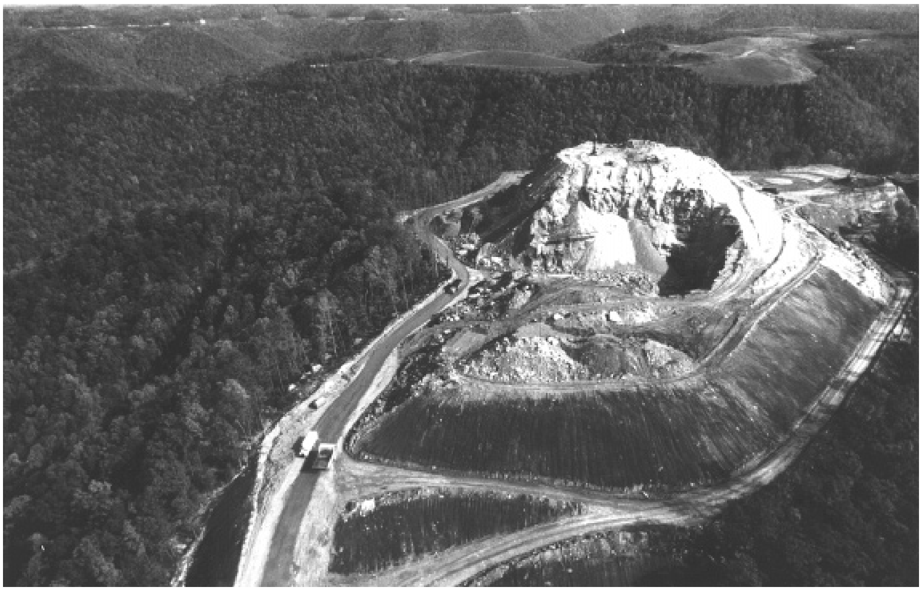

Figure 2. Coal mining in West Virginia using a technique known as 'mountaintop removal' in which miners cart away the entire top of a hill or ridge in order to gain access to coal seams beneath. Up to 150 m of hilltop may be dumped into nearby gullies and ravines, forming massive anthropogenic valley fills. Photograph by Lyntha Eiler; courtesy of American Folklife Center, US Library of Congress

Figure 1b is the resulting map of the spatial distribution of geomorphic activity of rivers as measured by yield of clastic and dissolved sediment from a grid cell.

## DISCUSSION

By the measures I have adopted, the geomorphic activity of humans in the United States is concentrated in the eastern part of the country, and particularly in the corridor from New York to Chicago (Figure 1a). This is consistent with the observations one might make on a flight across the country on a clear day. The major peak near the middle of this area is a consequence of coal mining activity in West Virginia and neighbouring states (Figure 2). Also readily distinguished are the influences of major population centres such as Denver, Salt Lake City, the Los Angeles–San Diego corridor and Seattle. The comparatively high human impact in the Midwest reflects the contribution of agriculture to the sediment loads of rivers.

In contrast, the geomorphic activity of rivers is concentrated in the west. This is because sediment yields are highest where precipitation is about 300 mm $a^{-1}$ and vegetation is thus sparse (Langbein and Schumm, 1958), and because relief is higher in the west.

The environmental impacts of the earth-moving activities of humans have yet to be explored thoroughly. Certain effects are well known. Among the most important is loss of arable land, in part because fertile ground is destroyed or covered with sterile materials (such as asphalt pavement made from sand and gravel – trucked from somewhere – combined with a bituminous binder), and in part because soil loosened in ploughing is carried away by wind and water. In the USA, we are losing soil at about 17 times the rate at which it is being formed. Combined with the current rate of population growth this will, by the year 2050, reduce the number of farm acres per person to one-third of its present value or half of that necessary for a sustainable abundant diverse food supply, such as we have now (D. Pimental, lecture, March 1995). Also noteworthy is environmental degradation resulting from leaching of noxious compounds from earth that has been displaced by human activities. Less well understood are the effects on ecosystems.

Unless population growth is brought under control or our standard of living is allowed to deteriorate significantly, the rate at which we move earth can only increase in the future.

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